Claims

1. A method of designing an intraocular correction lens capable of reducing aberrations of an eye after its implantation and adapted to be placed between the cornea and the capsular bag of the eye, comprising the steps of:
   - (i) measuring the wavefront aberration of the uncorrected eye using a wavefront sensor;
   - (ii) measuring the shape of at least one corneal surface in the eye using a corneal topographer;
   - (iii) characterizing the at least one corneal surface and a lens located in the capsular bag of the eye comprising said cornea as mathematical models;
   - (iv) calculating the resulting aberrations of said corneal surface(s) and the lens in said capsular bag by employing said mathematical models;
   - (v) selecting an optical power of the intraocular correction lens;
   - (vi) modeling the intraocular correction lens such that a wavefront arriving from an optical system comprising said intraocular correction lens and the mathematical models of said corneal and said lens in the capsular bag obtains reduced aberrations.

2. A method according to claim 1, wherein said corneal surface(s) and said lens in the capsular bag are characterized in terms of a conoid of rotation

3. A method according to claim 1 wherein said corneal surface(s) and said lens in the capsular bag are characterized in terms of polynomials.

4. A method according to claim 3, wherein said corneal surface(s) and said lens in the capsular bag are characterized in terms of linear combinations of polynomials.

5. A method according to claim 1, wherein the characterizing of the capsular bag lens as a mathematical model is accomplished by using values from measurements of the wavefront aberration of the whole eye and subtracting values from measurements of the wavefront aberration of only the cornea.

6. A method according to claim 5, wherein the wavefront aberration of the whole eye is measured using a wavefront sensor and the shape of the cornea is measured using topographical measurement methods.

7. A method according to claim 1, wherein said optical system further comprises complementary means for optical correction, such as spectacles or an ophthalmic correction lens.

8. A method according to claim 1, wherein estimations of the refractive powers of the cornea and the lens in the capsular bag and axial eye lengths designate the selection of optical power of the correction lens.

9. A method according to claim 3, wherein an optical system comprising said model of the cornea and the lens in the capsular bag and the modeled intraocular correction lens provides for a wavefront substantially reduced from aberrations as expressed by at least one of said polynomials.

10. A method according to claim 1, wherein modeling the intraocular correction lens includes selecting the anterior radius and surface shape of the lens, the posterior radius and surface shape of the lens, lens thickness and refractive index of the lens.

11. A method according to claim 10, wherein an aspheric component of the anterior surface is selected while the model lens has predetermined central radii, lens thickness and refractive index.

12. A method according to claim 1, wherein the intraocular correction lens is adapted to be implanted in the posterior chamber of the eye between iris and the capsular bag, the method further comprising the steps of:

(i) estimating the anterior radius of the lens in the capsular bag in its non-accommodated state ;

(ii) selecting a posterior central radius of the correction lens different to that of the lens in the capsular bag in its non-accommodated state;

(iii) determining the total correction lens vault based on the data arriving from steps (i) and (ii);

(iv) selecting a flawless curve free from points of inflection representing the intersection of the posterior surface and a plane containing the optical axis so as to provide an aspheric posterior correction lens surface.

13. A method according to claim 1, wherein the intraocular correction lens is adapted to be implanted in the anterior chamber of the eye and/or fixated to iris.

14. A method according to claim 1 including characterizing the front corneal surface of an individual by means of topographical measurements and expressing the corneal aberrations as a combination of polynomials.

15. A method according to claim 14 including characterizing the front and rear corneal surfaces of an individual by means of topographical measurements and expressing the total aberration of the cornea as a combination of polynomials.

16. A method according to claim 1, including characterizing corneal surfaces and natural lenses of a selected population and expressing average aberrations of cornea and natural lens of said population as combinations of polynomials.

17. A method according to claim 1, comprising the further steps of:

(v) calculating the aberrations of a wavefront arriving from said optical system;
(vi) determining if the modeled intraocular correction lens has provided sufficient reduction in aberrations in the wavefront arriving from said optical system; and optionally re-modeling the intraocular correction lens until a sufficient reduction is obtained.

18. A method according to claim 17, wherein said aberrations are expressed as linear combination of polynomials.

19. A method according to claim 18, wherein the re-modeling includes modifying one or several of the anterior surface and curvature, the posterior radius and surface, lens thickness and refractive index of the correction lens.

20. A method according to claim 3 or 4, wherein said polynomials are Seidel or Zernike polynomials.

21. A method according to claim 20, comprising the steps of:
    (i) expressing the aberrations of the cornea and the lens in the capsular bag as linear combinations of Zernike polynomials;
    (ii) determining the Zernike coefficients that describe the shape of the cornea and the capsular bag lens;
    (iii) modeling the intraocular correction lens such that a wavefront passing an optical system comprising said modeled correction lens and the Zernike polynomial models of the capsular bag lens and the cornea achieves a sufficient reduction of Zernike coefficients of the resulting wavefront aberration of the system.

22. A method according to claim 21, further comprising the steps of :
    (iv) calculating the Zernike coefficients of a wavefront resulting from the optical system;
    (v) determining if said intraocular correction lens has provided a sufficient reduction of Zernike coefficients; and optionally re-modeling said lens until a sufficient reduction in said coefficients is obtained.

23. A method according to claim 22, comprising sufficiently reducing Zernike coefficients referring to spherical aberration.

24. A method according to claim 22, comprising sufficiently reducing Zernike coefficients referring to aberrations above the fourth order.

25. A method according to claim 23, comprising sufficiently reducing the 11th Zernike coefficient of a wavefront from the optical system, so as to obtain an eye sufficiently free from spherical aberration.

26. A method according to claim 22, wherein the re-modeling includes modifying one or several of the anterior radius and surface shape, the posterior radius and surface shape, lens thickness and refractive index of the correction lens.

27. A method according to claim 26, comprising modifying the anterior surface shape of the correction lens until a sufficient reduction in aberrations is obtained.

28. A method according to claim 20, comprising modeling a correction lens such that the optical system provides reduction of spherical and cylindrical aberration terms as expressed in Seidel or Zernike polynomials in a wave front having passed through the system.

29. A method according to claim 28, obtaining a reduction in higher order aberration terms.

30. A method according to claim 9 comprising:

(i) characterizing corneal surfaces and lenses located in the capsular bags of a selected population and expressing each cornea and each capsular bag lens as a linear combination of polynomials;
(ii) comparing polynomial coefficients between different pairs of individual corneas and capsular bag lenses;
(iii) selecting one nominal coefficient value from an individual cornea and capsular bag lens;
(iv) modeling a correction lens such that a wavefront arriving from an optical system comprising said correction lens and the polynomial models of the lens in the capsular bag and the cornea sufficiently reduces said nominal coefficient value.

31. A method according to claim 30, wherein said polynomial coefficient refers to the Zernike aberration term expressing spherical aberration.

32. A method according to claim 30, wherein said nominal coefficient value is the lowest within the selected population.

33. A method of selecting an intraocular correction lens that is capable of reducing aberrations of the eye after its implantation comprising the steps of:

(i) characterizing at least one corneal surface and a lens located in the capsular bag of the eye comprising said cornea as mathematical models;

(ii) calculating the resulting aberrations of said corneal surface(s) and the lens in said capsular bag by employing said mathematical models;

(iii) selecting an intraocular correction lens having a suitable optical power from a plurality of lenses having same power, but different aberrations;

(iv) determining if an optical system comprising said selected correction lens and said mathematical models of the lens in the capsular bag and the cornea sufficiently reduces the aberrations.

34. A method according to claim 33 further comprising the steps of:

(v) calculating the aberrations of a wave front arriving from said optical system;

(vi) determining if said selected intraocular correction lens has provided a sufficient reduction in aberrations in a wavefront arriving from said optical system; and optionally repeating steps (iii) and (iv) by selecting at least one new correction lens having the same optical power until finding a correction lens capable of sufficiently reducing the aberrations.

35. A method according to claim 33, wherein said corneal surface(s) and said lens in the capsular bag are characterized in terms of a conoid of rotation.

36. A method according to claim 33 wherein said corneal surface(s) and said lens in the capsular bag are characterized in terms of polynomials.

37. A method according to claim 36, wherein said corneal surface(s) and said lens in the capsular bag are characterized in terms of linear combinations of polynomials.

38. A method according to claim 33, wherein the total aberration of the eye is measured together with the aberration of only the cornea, these measurements giving the individual aberrations of the cornea and the capsular bag lens.

39. A method according to claim 38, wherein the total aberration of the eye is measured using a wavefront sensor and the aberration of the cornea is measured using topographical measurement methods.

40. A method according to claim 33 or 34, wherein said optical system further comprises complementary means for optical correction, such as spectacles or an ophthalmic correction lens.

41. A method according to claim 33, wherein estimations of the refractive powers of the cornea and the lens in the capsular bag and axial eye lengths designate the selection of correction lens optical power.

42. A method according to claim 36 or 37, wherein an optical system comprising said models of the cornea and the lens in the capsular bag and the selected intraocular correction lens provides for a wavefront substantially reduced from aberrations as expressed by at least one of said polynomials.

43. A method according to claim 33, wherein the intraocular correction lens is adapted to be implanted in the posterior chamber of the eye between iris and the capsular bag, the method further comprising the steps of:

(v) estimating the anterior radius of the lens in the capsular bag in its non-accommodated state ;

(vi) selecting a posterior central radius of the correction lens different to that of the lens in the capsular bag in its non-accommodated state;

(vii) determining the total correction lens vault based on the data arriving from steps (i) and (ii);

(viii) selecting a flawless curve free from points of inflection representing the intersection of the posterior surface and a plane containing the optical axis so as to provide an aspheric posterior correction lens surface.

44. A method according to claim 33, wherein the intraocular correction lens is adapted to be implanted in the anterior chamber of the eye and fixated to iris.

45. A method according to claim 33, including characterizing the front corneal surface of an individual by means of topographical measurements and expressing the corneal aberrations as a combination of polynomials.

46. A method according to claim 45, including characterizing the front and rear corneal surfaces of an individual by means of topographical measurements and expressing the total aberration of the corneal as a combination of polynomials.

47. A method according to claim 33, including characterizing corneal surfaces and lenses in capsular bags of a selected population and expressing average aberrations of the cornea and the lens in the capsular bag of said population as combinations of polynomials.

48. A method according to claim 42, wherein said polynomials are Seidel or Zernike polynomials.

49. A method according to claim 48, comprising the steps of:

(i) determining the wavefront aberration of the cornea and the lens in the capsular bag;
(ii) expressing the aberrations of the cornea and the lens in the capsular bag as linear combinations of Zernike polynomials;
(iii) selecting the intraocular correction lens such that a wavefront passing an optical system comprising said correction lens and the Zernike polynomial models of the cornea and the lens in the capsular bag achieves a sufficient reduction in Zernike coefficients.

50. A method according to claim 49, further comprising the steps of :

(iv) calculating the Zernike coefficients of a wavefront resulting from the optical system;
(v) determining if said intraocular correction lens has provided a sufficient reduction of Zernike coefficients; and optionally selecting a new lens until a sufficient reduction in said coefficients is obtained.

51. A method according to claim 49 or 50, comprising determining Zernike polynomials up to the 4th order.

52. A method according to claim 51 comprising sufficiently reducing Zernike coefficients referring to spherical aberration.

53. A method according to claim 52 comprising sufficiently reducing Zernike coefficients above the fourth order.

54. A method according to claim 52 comprising sufficiently reducing the 11th Zernike coefficient of a wavefront arriving from the optical system, so as to obtain an eye sufficiently free from spherical aberration.

55. A method according to claim 45 comprising selecting an intraocular correction lens such that the optical system provides reduction of spherical aberration terms as expressed in Seidel or Zernike polynomials in a wave front having passed through the system.

56. A method according to claim 45, wherein reduction in higher order aberration terms is accomplished.

57. A method according to claim 33 characterized by selecting an intraocular correction lens from a kit comprising lenses with a suitable power range and within each power range a plurality of lenses having different aberrations.

58. A method according to claim 57, wherein said aberrations are spherical aberrations.

59. A method according to claim 57, wherein said correction lenses within each power range have surfaces with different aspheric components.

60. A method according to claim 59, wherein said surfaces are the anterior surfaces.

61. An intraocular correction lens obtained in accordance with any of claims 1 to 60, capable of, in combination with a lens in the capsular bag of an eye, transferring a wavefront having passed through the cornea of the eye into a substantially spherical wavefront having its center in the retina of the eye.

62. An intraocular correction lens according to claim 61, capable of compensating for the aberrations of a model of the cornea and the lens in the capsular bag designed from a suitable population, such that a wavefront arriving from an optical system comprising said correction

lens and said model of the cornea and the lens in the capsular bag obtains substantially reduced aberrations.

63. An intraocular correction lens according to claim 62, wherein said model of the cornea and the lens in the capsular bag includes average aberration terms calculated from characterizing individual corneas and capsular bag lenses and expressing them in mathematical terms so as to obtain individual aberration terms.

64. An intraocular correction lens according to claim 63, wherein said aberration terms is a linear combination of Zernike polynomials.

65. An intraocular correction lens according to claim 64 capable of reducing aberration terms expressed in Zernike polynomials of said model of the cornea and the lens in the capsular bag, such that a wavefront arriving from an optical system comprising said correction lens and said model of the cornea and the lens in the capsular bag obtains substantially reduced spherical aberration.

66. An intraocular correction lens according to claim 65 capable of reducing the 11^{th} Zernike term of the 4^{th} order.

67. An intraocular correction lens having at least one aspheric surface which when its aberrations are expressed as a linear combination of polynomial terms, is capable of, in combination with a lens in the capsular bag of an eye, reducing similar such aberration terms obtained in a wavefront having passed the cornea, thereby obtaining an eye sufficiently free from aberrations.

68. An intraocular correction lens according to claim 67, wherein said aspheric surface is the anterior surface of the lens.

69. An intraocular correction lens according to claim 67, wherein said aspheric surface is the posterior surface of the lens.

70. An intraocular correction lens according to claim 69, wherein said polynomial terms are Zernike polynomials.

71. An intraocular correction lens according to claim 70 capable of reducing polynomial terms representing spherical aberrations and astigmatism.

72. A lens according to claim 71, capable of reducing the 11^{th} Zernike polynomial term of the 4^{th} order.

73. An intraocular correction lens according to claim 72 made from a soft biocompatible material.

74. An intraocular correction lens according to claim 73 made of silicone.

75. An intraocular correction lens according to claim 73 made of hydrogel.

76. An intraocular correction lens according to claim 72 made of a rigid biocompatible material.

77. An intraocular correction lens according to claim 67 adapted to be implanted in the posterior chamber of the eye between iris and the capsular bag comprising a centrally located optical part capable of providing an optical correction and a peripherally located supporting element capable of maintaining said optical part in said central location, said optical part and said support element together having a concave posterior surface which is part of a non-spherical surface, the intersection between said non-spherical surface and any plane containing the optical axis representing a flawless curve free from discontinuities and points of inflection.

78. An intraocular correction lens according to claim 77 adapted to be implanted in the anterior chamber of the eye and fixated to iris.

79. A method for improving the visual quality of an eye, characterized by implanting an intraocular correction lens according to the claims 61-78.

80. A method according to claim 79, wherein spectacles or correction lenses are provided outside the eye to further improve the visual quality.

81. A method according to claim 79, wherein the cornea of the patient receiving the intraocular correction lens has been modified by means of a laser.

82. A method of improving the visual quality of an eye, **characterized by** the steps of:

- conducting corneal surgery on the eye;
- allowing the cornea to recover;
- performing a wavefront analysis of the eye; and
- designing a correction lens according to any one of the claims 1-15, 17-29,33-46 and 48-60; and
- implanting the correction lens in the eye.